

**IDENTIFYING THE TECHNIQUES AND CHALLENGES
OF GPS SURVEYING FOR VERTICAL ALIGNMENTS
IN HIGH-RISE BUILDINGS**

Abdul Wahid Mohamed Safith

(138424U)

Degree of Master of Science

Department of Building Economics

University of Moratuwa
Sri Lanka

September 2016

IDENTIFYING THE TECHNIQUES AND CHALLENGES OF GPS SURVEYING FOR VERTICAL ALIGNMENTS IN HIGH-RISE BUILDINGS

Abdul Wahid Mohamed Safith

(138424U)

Dissertation submitted in partial fulfillment of the requirements for the degree of
Master of Science in Project Management

Department of Building Economics

University of Moratuwa
Sri Lanka

September 2016

DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Master Dissertation under my supervision.

Signature of the supervisor:

Date:

DEDICATION

This is dedicated to

My Parents

&

beloved wife M.L. Fathima Mafaisa

for their love, support and encouragement

ACKNOWLEDGEMENT

It is my obligation to acknowledge and be ever grateful to those who have contributed to complete the task successfully. First of all, I would like to express my heartfelt gratitude to my supervisor Prof. Archt. Lalith De Silva who is the Dean of the Faculty of Architecture for his great inspirational support, advices and guidance throughout the research in his busy schedule.

I take this opportunity to acknowledge and emphasize the gratefulness to Dr.Y.G. Sandanayake, Head, Department of Building Economics, Ch.QS. Indunil Seneviratne, the Program Director, Ch.QS. Dr. Nirodha Fernando, Research Coordinator and all other lecturers for facilitating and making necessary arrangement for the study. Further I would like to extend the thankfulness to all other academic and non-academic staff members of the faculty for their direct and indirect supports for the successful journey of the study.

My special appreciation goes to Prof Archt. Samitha Manawadu for his support and guidance to do the case study at The Lotus Tower. I would like to extent further the gratitude to Licensed Chief Surveyor Mr. C.S. Liyanage and Project Consultant Unit of the Lotus Tower, Mr. A.W.M. Irshan, Construction Manager and the Project Management Unit of ‘The Elements’ and the Project Management Unit of the ‘Clearpoint’ of MAGA Engineering (Pvt.) Ltd for facilitating and making necessary arrangement for the case studies and experiments in their projects.

My sincere gratitude goes to Mr. Chaminda Senavirathna, Manager (Surveying & GIS) and other staff members of SULECO (Pvt.) Ltd. for facilitating the case studies and experiments by field observations and processing with their complete set of GPS instruments, software and CORSnet positional correction broadcasting network.

Further, I would like to extend the gratitude to Mr. S.D.P.J. Dampegama, Additional Surveyor General, Survey Department, Sri Lanka, Mr. Joel Van Cranenbroeck, Former Business Technology Manager at Leica Geosystems, and all other academic and industrial professionals who have shared their expertise and experience via interviews and questionnaire surveys to add more value to the study.

ABSTRACT

Identifying the Techniques and Challenges of GPS Surveying for Vertical Alignments in High-Rise Buildings

Vertical alignment in high-rise building is a very important aspect. In order to manage the growing demand for spaces in urban cities, the people are now interested in construction of super high-rise buildings. The architects are nowadays interested in improvising untypical complicated morphology in building designs which increase the difficulties in surveying for vertical alignments. Consequently the surveyors are themselves forced to find alternative survey techniques to manage the difficulties. Though the GPS survey techniques are applicable like in other constructions, the majority of the construction society is still depended on the traditional survey methods.

As per the existing data sources, operational and spaces related challenges of GPS surveying are common for any kind of GPS applications; and though the GPS survey techniques are applicable for vertical alignment in high-rise buildings, there is lack of data sources to explicitly expose the applicability of different GPS survey techniques and the challenges to be considered in such applications. This study has been oriented to find out the best suitable GPS survey technique for the vertical alignments in high-rise buildings by checking the applicability of all five basic GPS techniques with their accuracy, efficiency, time consuming and cost implications while focusing on identifying further practical challenges apart from the already identified operational and space related problems.

The findings prove that the GPS techniques can be used for vertical alignments in high-rise buildings and the best technique among them is Static GPS with the combination of traditional survey methods; and there are some practical challenges to be considered in such GPS applications for vertical alignments in high-rise buildings. The findings have been attained by analyzing the reliable data gained through experts' comments, case studies and experiments.

Keywords: *High-Rise Building, Vertical Alignment, GPS Techniques, CORS, CWCSS*

TABLE OF CONTENTS

CONTENT	PAGE
DECLARATION.....	i
DEDICATION.....	ii
ACKNOWLEDGEMENT.....	iii
ABSTRACT.....	iv
LIST OF FIGURES.....	x
LIST OF TABLES.....	xii
LIST OF ABBREVIATIONS.....	xiv
LIST OF APPENDICES.....	xv
 CHAPTER ONE.....	 1
1 INTRODUCTION.....	1
1.1 Background	1
1.2 Research Problem.....	4
1.3 Research Questions	5
1.4 Aim.....	5
1.5 Objectives.....	5
1.6 Significance of the Research	6
1.7 Limitations of the Research.....	6
1.8 Overview of the Research Methodology	7
1.9 Outline of the Dissertation	10

CHAPTER TWO.....	11
2 LITERATURE REVIEW.....	11
2.1 Introduction	11
2.2 GPS in High-Rise Building Construction	11
2.3 Overview on Global Positioning System (GPS)	13
2.3.1 Principle of GPS Positioning	15
2.3.2 Differential GPS (DGPS).....	16
2.3.3 GPS Survey Techniques in High-Rise Buildings	17
2.3.3.1 Static Positioning.....	17
2.3.3.2 Rapid Static	18
2.3.3.3 Reoccupation	18
2.3.3.4 Kinematic Positioning	19
2.3.3.5 Real Time Kinematic (RTK).....	20
2.3.4 CORS and VRS.....	20
2.4 Site Selection for GPS Surveys	21
2.5 Challenges in Applying GPS Surveying for Verticality	23
2.5.1 Building Movement	23
2.5.2 Safety.....	24
2.5.3 Shape of the Structure	24
2.5.4 Nature of Environment.....	24
2.5.5 Quality Control	25
2.5.6 Operation of Reference Receivers	25
2.5.7 Distance from Reference Receivers	26
2.5.8 Data Latency	26
2.5.9 Ambiguity Resolution (AR).....	27
2.5.10 Difficult to Determine the Observation Span for AR	27

2.5.11	Need of Powerful Communication Link	28
2.5.12	Expensiveness	28
2.5.13	Cycle Slip	29
2.5.14	Electromagnetic Signal Interferences	29
2.5.15	Number of Visible Satellites and Selective Availability.....	30
2.6	GPS against Traditional Surveying	30
2.7	Core Wall Control Survey System (CWCSS).....	31
2.8	Summary	34
CHAPTER THREE.....		35
3	METHODOLOGY.....	35
3.1	Introduction	35
3.2	Research Design	35
3.3	Data Collection.....	37
3.3.1	Phase 1 – Literature Survey and Unstructured Interviews.....	37
3.3.2	Phase 2 – Questionnaire Survey and Semi-Structured Interviews.....	38
3.3.3	Phase 3 – Case Studies and Experiments.....	38
3.3.4	Population and Sample.....	38
3.3.5	Questionnaire	40
3.3.6	Interviews	41
3.3.7	Method of Data Analysis	42
3.4	Case Studies and Experiments	46
3.4.1	2D Similarity Coordinate Transformation	46
3.4.2	Least Square Adjustment	49
3.4.3	Total RMS Error	50
3.4.4	Paired Comparison Analysis and Decision Matrix	50
3.5	Summary	51

CHAPTER FOUR.....	52
4 DATA ANALYSIS.....	52
4.1 Introduction	52
4.2 Background and Experience of the Respondents	52
4.3 Problems in Traditional Surveying Methods	59
4.4 GPS against Traditional Survey Methods	63
4.5 GPS Survey Techniques in High-Rise Buildings.....	65
4.5.1 Comparison of Accuracy of GPS Survey Techniques	67
4.5.2 Challenges in GPS Surveying	68
4.6 Summary	73
CHAPTER FIVE.....	74
5 CASE STUDIES, EXPERIMENTS AND DISCUSSIONS.....	74
5.1 Introduction	74
5.2 Case Studies	74
5.2.1 Case 1: Traditional Survey Methods and RTK GPS in ‘The Colombo Lotus Tower’	75
5.2.1.1 Laser Plummet.....	76
5.2.1.2 RTK GPS.....	77
5.2.2 Case 2: Traditional Survey Methods at ‘The Elements’ by Fairway	79
5.2.3 Case 3: Traditional Survey Methods at ‘CLEARPOINT’ Residencies ..	79
5.3 Experiment on GPS Techniques	79
5.3.1 Experiment at ‘The Elements’ by Fairway	81
5.3.1.1 Coordinate Transformation	81
5.3.1.2 GPS Surveys and Processing.....	82
5.3.2 Experiment at ‘CLEARPOINT’ Residencies.....	86
5.3.2.1 Coordinate Transformation	86
5.3.2.2 GPS Surveys and Processing.....	87

5.4	Comparison of GPS Techniques and Decision Making.....	91
5.5	Comparison between Traditional Survey Methods and GPS Surveys	94
5.6	Problems Faced	96
5.7	Summary	97
CHAPTER SIX.....		99
6	CONCLUSIONS AND RECOMMENDATIONS.....	99
6.1	Introduction	99
6.2	Conclusions	99
6.2.1	GPS Survey Techniques in High-Rise Buildings	99
6.2.2	Challenges	101
6.3	Recommendations	102
6.4	Future Researches	104
REFERENCES.....		105

LIST OF FIGURES

	Page
Figure 1.1: Research Approach.....	9
Figure 2.1: Satellite Constellation.....	14
Figure 2.2: Differential GPS	16
Figure 2.3: CORS and VRS	21
Figure 2.4 : Cut-off Angle.....	22
Figure 2.5: CWCSS Data Fusion System – Straight Real Line	31
Figure 2.6: CWCSS Data Fusion System – Curved Real Line.....	33
Figure 3.1: Body of Knowledge.....	36
Figure 3.2: Translation.....	47
Figure 3.3: Scaling	47
Figure 3.4: Rotation	48
Figure 4.1: Respondents.....	53
Figure 4.2: Experience in Construction Surveying.....	54
Figure 4.3: Experience in GPS Surveying	55
Figure 4.4: Experience in High-Rise Building Construction.....	56
Figure 4.5: Number of Stories of Buildings involved.....	57
Figure 4.6: Methods of Surveying applied	58
Figure 4.7: GPS Techniques applied	59
Figure 4.8 : Problems - Traditional Survey Methods	61
Figure 4.9 : RII of the Problems - Traditional Survey Methods	62
Figure 4.10 : GPS against Traditional Survey Methods	63
Figure 4.11 : GPS against Traditional Survey Methods	64
Figure 4.12 : GPS against Traditional Survey Methods	64

Figure 4.13 : GPS against Traditional Survey Methods	65
Figure 4.14 : GPS Techniques recommended for Vertical Alignment	66
Figure 4.15 : GPS Techniques recommended for Vertical Alignment	67
Figure 4.16 : Assessment of Accuracy of GPS Techniques	68
Figure 4.17: GPS Surveys in High-Rise Buildings.....	69
Figure 4.18 : Challenges in GPS Surveying	71
Figure 4.19 :RII of the Challenges – GPS Surveying	72
Figure 5.1: RTK GPS Observation at The Lotus Tower	77
Figure 5.2 : GPS Observation at ‘The Elements’ Site	83
Figure 5.3 : GPS Observation at ‘Clearpoint’ Site.....	88

LIST OF TABLES

	Page
Table 3.1: Level of Experience	42
Table 3.2: Building Categories (Frederick & Kent, 2007)	42
Table 3.3: Responses, Points and Type.....	43
Table 3.4: Types of Responses	44
Table 3.5: Types of Assessments	45
Table 3.6: Types of Recommendations	45
Table 3.7: Level of Accuracy.....	46
Table 4.1: Background of the Respondents	52
Table 4.2: Workplaces of the Respondents.....	53
Table 4.3: Experience in Construction Surveying	54
Table 4.4: Experience in GPS Surveying	55
Table 4.5: Experience in High-Rise Building Construction	56
Table 4.6: Number of Stories of Buildings involved	56
Table 4.7: Methods of Surveying applied.....	57
Table 4.8: GPS Techniques applied.....	58
Table 4.9 : RII and Ranks of Problems – Traditional Survey Methods.....	60
Table 4.10: GPS against Traditional Survey Methods.....	63
Table 4.11 : GPS Techniques Recommended for Vertical Alignment	66
Table 4.12: Assessment of Accuracy of GPS Techniques.....	67
Table 4.13: GPS Surveys in High-Rise Buildings	68
Table 4.14 : Challenges in GPS Surveying.....	70
Table 5.1: Allowable Deviation in Verticality.....	78
Table 5.2: Accuracy Specification of S82-V RTK GNSS Receivers	80

Table 5.3: Accuracy Specification of CORS (CORSnet)	81
Table 5.4: Coordinates of Control Points	82
Table 5.5: Static GPS - Coordinates and RMS Error.....	84
Table 5.6: Fast-Static GPS - Coordinates and RMS Error.....	84
Table 5.7: Pseudo-Kinematic GPS - Coordinates and RMS Error	85
Table 5.8: Kinematic GPS - Coordinates and RMS Error	85
Table 5.9: RTK GPS - Coordinates and RMS Error.....	86
Table 5.10: Coordinates of Control Points	87
Table 5.11: Static GPS - Coordinates and RMS Error.....	89
Table 5.12: Fast-Static GPS - Coordinates and RMS Error.....	89
Table 5.13: Pseudo-Kinematic GPS - Coordinates and RMS Error	89
Table 5.14: Kinematic GPS - Coordinates and RMS Error	90
Table 5.15: RTK GPS - Coordinates and RMS Error.....	90
Table 5.16: Rank of Accuracy of GPS Techniques	91
Table 5.17: Paired Comparison Analysis.....	92
Table 5.18: Decision Matrix	93
Table 5.19: GPS vs Traditional Methods.....	95

LIST OF ABBREVIATIONS

Abbreviation	Description
AR	Ambiguity Resolution
BIM	Building Information Modeling
CAD	Computer Aided Design
CORS	Continuous Operating Reference Stations
CWCSS	Core Wall Control Survey System
DGPS	Differential Global Positioning System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
KSA	Kingdom of Saudi Arabia
MSS	Mobile Satellite Service
RF	Radio Frequency
RII	Relative Importance Index
RTK	Real Time Kinematic
SA	Selective Availability
UAE	United Arab Emirates
UHF	Ultra High Frequency
US	United States
UWB	Ultra-Wideband
VHF	Very High Frequency
VRS	Virtual Reference Station

LIST OF APPENDICES

Appendix	Description	Page
Appendix - A:	Questinnnaire	112
Appendix - B :	Transformation Parameters (WGS84 to SLD99).....	121
Appendix - C :	Coordinate Transformation Matrices – ‘The Element’	122
Appendix - D :	Coordinate Transformation Matrices – ‘Clearpoint’	123